INFLUENCE OF ARTIFICIAL HEATING ON THE CLIMATE OF CITIES.

By GEORGE W. MINDLING, Observer.

Mr. Reginald P. Bolton, president of the American Society of Heating and Ventilating Engineers, in a paper presented at a recent meeting of that body, has made some interesting statements regarding the effects upon weather conditions produced by the enormous fuel consumption in New York City, of which the most important are substantially as follows: (1) That the rapidly increasing consumption of fuel has lessened the number of days with a temperature as low as or lower than zero; (2) that it has produced an increase in the number of cloudless days; (3) that it is causing a progressive decrease in precipitation, particularly in the winter months; (4) that it has lowered the relative humidity of the air over the city approximately 7 per cent; and (5) that all these effects are physically determined by the amount of heat artificially produced in the city, which, according to Mr. Bolton's computations, is sufficient to raise the temperature of the air 4.94° F. over the entire area of the city (326 square miles) to the height of 1 mile. These conclusions are important if they are well founded, and therefore it is worth while to examine them in the light of the most reliable meteorological investigations and of those records that have been continued without interruption for periods of 20 to 90 years or more at New York and in cities and towns of various sizes not far away.

It is obvious that, if Mr. Bolton's theory is correct, the temperature records for New York should show higher averages in the last 20 or 30 years, particularly in the winter months, than for corresponding periods before the middle of the last century, and this increase in temperature should exceed that appearing for corresponding periods in the records of any of the smaller cities near by—for example, New Haven. Furthermore, it is obvious that if the mean temperature of the free air over New York, as represented by the locations where the Weather Bureau records have been made, has not been noticeably affected by artificial heating, then the recent variations in the precipitation, humidity, and cloudiness must be ascribed to some other cause. A discussion of the records of temperature with reference to these points appears farther on.

It must be admitted, of course, that there are differences of temperature between sites in the open country and near-by cities. The existence of such differences is well known and has been studied by such meteorologists as Rouen, Hann, Hellmann, and many American investigators. The differences vary with the weather conditions, being greatest when the sky is clear and the wind movement least. City and country sites of equal elevation and within a few miles of each other have occasionally shown a difference in temperature as great as 20° F., but the evidence presented in this article seems to indicate that the higher mean temperatures observed in cities are not due to artificial heating; that they are limited chiefly to the spaces near the surface where the wind movement is obstructed, and that artificial heating has no appreciable effect on the free air immediately over the cities.

Hellmann found that Berlin is 0.54° F. warmer than the surrounding country in winter, 1.08° warmer in spring and summer, and 0.72° warmer in autumn. It is evident that, if these differences were to be accounted for by artificial heating, they should be greatest in winter and least in summer; but, so far as the writer is able to ascertain, these differences, not only in Berlin but in all places where they have been studied, are least during the heating season.

It is not the heat produced within the buildings, but the position of the buildings, that is chiefly accountable for the higher temperatures in the heart of cities. Contributory causes are to be found in the materials used in walls and pavements, the differences in drainage, and in the character of the surface. The position of buildings in a city obstructs the natural movements of the air, while the continued reflection of solar energy from walls and pavements rapidly increases the temperature in the spaces sheltered from the winds. In the cities water is quickly conducted away by means of drains, sewers, etc., so that the ground is quite effectually prevented from becoming wet, where it is not actually sheltered by buildings or pavements, while in the country the ground everywhere is well adapted to the absorption of the rain water as a result either of tillage or of being covered with vegetation that checks the process of drainage. Consequently, when the sun appears, the increase in temperature is retarded by the process of evaporation in the country much more than in the city, due allowance being made for the sprinkling of the streets. A considerable part of the heat thus accumulated in the cities is not lost during the night for reasons stated farther on, and the nights are, therefore, much cooler in the country, especially in clear weather. It is readily seen that the causes mentioned are most active during the summer, which accounts for the fact that the greatest differences in temperature are observed during that season.

Hann's investigations led to the conclusion that the higher temperatures observed in the cities at night are due principally to the more rapid process of nocturnal radiation in the country. Unquestionably the more rapid radiation of heat in the country at night is caused by the absence of clouds of smoke such as usually hover over large cities. In a discussion read before the St. Louis Academy of Science, March 2, 1896, Hammon and Duenckle pointed out the great influence of clouds of smoke in producing the warmer nights of the cities. The underlying principle had been recognized many years before and is given practical application in frost fighting.

Hammon and Duenckle found that the average temperatures at the Weather Bureau and Forest Park Observatories in St. Louis showed a difference of 2.8° F. for a period of five years. At the Weather Bureau the thermometers were exposed 110 feet above the level of the street in the heart of the city and were closely surrounded by tall chimneys belching forth enormous quantities of smoke and were as much subject to the influence of artificial heating as they could be at any of the localities where Weather Bureau instruments have been exposed. Yet these able investigators, whose discussion

was published in the Monthly Weather Review for January, 1902, and is now universally regarded as authoritative, did not even mention the effect of artificial heating, finding that the observed differences were due chiefly to the difference in nocturnal radiation. It is worthy of note that the mean maximum (day) temperatures differed only 0.6°, while the mean minimum (night) temperatures differed by 4.6°, these at Forest Park averaging from 9.0° lower in September to 1.5° lower in December. The extreme differences ranged from 20° lower to 2° higher. A study of the observations showed that the greatest differences accompanied the clear skies of September, and the least were observed during the cloudiest months, March and December, the differences remaining small throughout the winter season. Marked exceptions to this rule occurred, but there is abundant evidence to show that they were due to such causes as clear skies and differences in wind velocity and depth of snow. The following remarks have been taken from the report of Hammon and Duenckle as published in the Monthly Weather Review:

> If two or more days showed a remarkable difference in the minimum temperatures at our two stations, as was the case in January, 1892, it was because the air remained calm and clear at the park, while the smoke appeared to be heaped up over the city. It thus appears that the principal cause of the difference in the minimum temperature readings at the Forest Park and Weather Bureau Observatories is the accumulation of smoke over the city, especially on nights when the sky is clear and the wind light. These conditions favor a rapid radiation of heat from the ground at the park, while the smoke over the city acts as a cloud covering and materially retards radiation.

Eaton's calculations (1877) showed that sufficient heat was developed by the burning of coal and gas in London to raise the mean temperature of a stratum of air 30 meters thick over an area of 118 square miles 1.2° C. an hour. But when allowance is made for the movement of the air at an average rate of 10 to 15 miles an hour, which is sufficient to replace practically all the air over the 118 square miles each hour, and for the fact that the heat artificially produced is bound to diffuse itself upward and outward indefinitely instead of being confined to a stratum of 30 meters thickness, it will be seen that the consumption of fuel is far less important in its relation to the climate than at first appears.

In the case of New York City in winter, Mr. Bolton concludes that—

> If to the volume of these gases of combustion we add the radiant heat and that imparted by convection from all sources, to which reference has been made, we find a total exceeding 4,000,000,000 heat units per 24 hours, which * * * would raise the temperature 4.94° F. over the entire area of the greater city, 326 square miles, to a height of a mile.

Assuming that these figures are correct, let us see what becomes of this heat under the influence of the wind movement at New York, an influence which Mr. Bolton evidently has overlooked. In the monthly and annual summaries contained in the reports of the Chief of the Weather Bureau we find that the average hourly velocity at New York varies from 12 to 18 miles during the winter months, the anemometer being exposed at an altitude of 350 feet. At greater altitudes the velocity of the wind is correspondingly higher, and for the entire stratum of air within a mile from the surface the average velocity for all the winter months is certainly not less than 18 miles an hour. (See Davis, Elementary Meteorology, p. 97.)

If New York were in the form of a square about 18 miles in breadth, this average velocity would be sufficient to renew practically all the air over the city once each hour, or 24 times daily. Therefore the heating effect of combustion, on which Mr. Bolton relies to raise the temperature 4.94°, would be but one twenty-fourth of that amount, or about two-tenths of a degree. But the city is not in the form of a square, and its position is such that the winds usually blow across it in the shortest direction. The city being about 6 to 9 miles wide (excluding water surfaces) and trending nearly northeast and southwest, it is crossed by the east, southeast, west, and northwest winds in such a manner that the air over it is renewed about two and a half times an hour, or 60 times daily on the average. Therefore during the prevalence of these winds, which, according to the most reliable records, covers fully two-thirds of the time, the heating effect of combustion upon the temperature of the free air is one-sixtieth of 4.94°, or somewhat less than one-tenth of 1°. It need only be suggested how insignificant this heating effect becomes under the influence of a strong northwest gale, such as generally precedes the principal cold waves of winter.

Of course, the heat artificially produced is not lost to as great a degree in the spaces near the surface that are sheltered from the wind, but from the foregoing it is evident that the temperature of the free air can not be appreciably affected by the heat of combustion. On the average the stratum of air whose temperature is subject to appreciable influence (say a change of one-third of a degree) from artificial heating can scarcely be more than 100 feet thick over the city as a whole, and were it possible to raise the temperature of this by artificial means as much as 50°, it would be equivalent to raising the average temperature of a stratum of air 1 mile in thickness less than 1°, which usually would not suffice to produce any apparent effect on the degree of cloudiness or on the relative humidity, and still less on the amount of precipitation.

If the influence of artificial heating is as great as Mr. Bolton has stated it to be, we should find the mean annual temperature at New York City not less than 2.5° higher during the last 30 years than in the 30 years ending in 1851, and the mean annual temperature should show a gradual increase during the intervening period. On examination of the records we find the mean annual temperature for the 30 years ending in 1851 to be 51.7°, while for the 30 years ending in 1910 it is only 0.5° higher. It will be seen that there has not been a gradual increase in the temperature and that the mean for the last decade was not higher than for some others. As in the case of all other stations, the records for New York exhibit slight variations that have been repeated again and again. The mean annual temperatures for successive periods of 10 years ending with 1910 are 52.1°, 50.7°, 51.0°, 52.3°, 51.2°, 51.7°, 52.5°, and 52.3°. The variations here shown furnish no evidence of any effect of artificial heating, since it appears that there have been repeated changes from lower to higher and from higher to lower, while the mean for the first decade given is almost the same as that for the last. It is known that variations such as those at New York and even greater are brought about by natural causes and must continue to occur indefinitely. The variations here indicated, in reality, constitute an evidence for what has been termed the

Brückner period, so called in honor of the celebrated German meteorologist whose investigations led him to the discovery that in most parts of the world "groups of relatively cool and rainy years alternate with groups of warmer and dryer years, the whole cycle having an average period of 35 years, though the actual length of any individual cycle may be as great as 50 years or as little as 20." (W. L. Moore, Descriptive Meteorology, p. 277.)

[The shading indicates the excess or deficiency of mean monthly and annual temperatures for the 30-year period ending with 1910 as compared with the means for the 30-year period 1822–1851.]

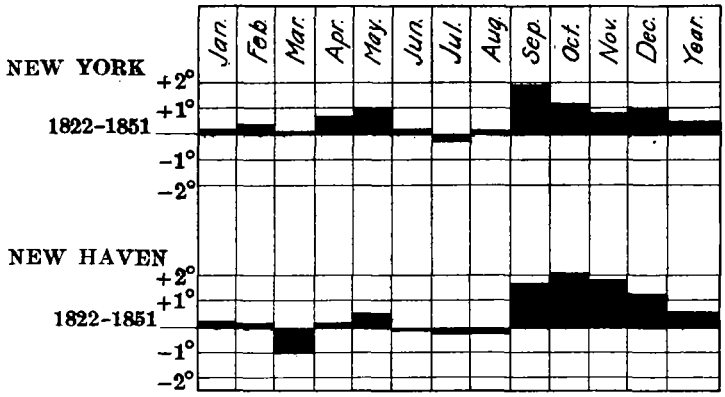


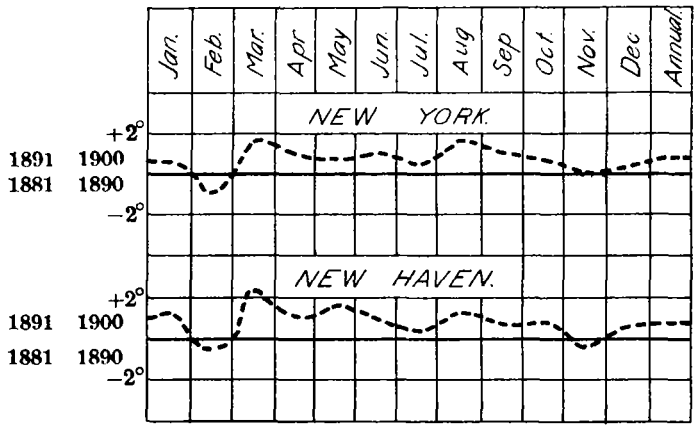
FIG. 1.—Comparison of mean temperatures for the 30-year periods ending in 1851 and 1910.

In connection with the preparation of this article the writer made a special study of the United States Weather Bureau records of temperature for many stations besides New York, particularly those of Philadelphia, Atlantic City, New Haven, and Setauket, which is situated near the middle of Long Island. These were selected without regard as to what the nature of their evidence might be, but were taken because they were the most satisfactory records available for points within a reasonable distance from New York, records not covering at least 20 years without interruption being of no special value in this study.

Table 1 and figures 1 and 2 serve to show the general agreement of the climatic variations in New York and places within a moderate distance where the amount of artificial heating is insignificant compared with that in New York. From Table 1 it appears that the mean annual temperature was generally higher for the period 1891–1900 than in either the preceding or following decade. From figure 1 it will be seen that the monthly means for January, March, April, and July show an increase in temperature during the last three decades, while in February and November there has been a continued decrease during the same period. Both increases and decreases appear in the other months, but the variations are quite similar at the several stations. The decrease in temperature during successive decades in February and during the last decade in November and December is not in accordance with the theory that artificial heating has a tendency to raise the temperature of the free air, while the increase found in the other winter months is not sufficient to indicate a higher average temperature for the heating season during the more recent years. If the increase in temperature at New York for January and March be ascribed to the influence of artificial heating, how shall it be accounted for in the little village of Setauket?

Mean monthly and annual temperatures for successive periods of 10 years each were obtained and the variations in these means from decade to decade were noted. (See Table 1.) It was desired to ascertain whether such variations as appear in the New York records are peculiar to that station or similar to those of other stations. Marked similarity was found in these variations at New York, Atlantic City, Setauket, and New Haven, where we should expect to find some resemblance, as these stations, being near each other and the ocean, are subject to similar vicissitudes of climate. (See fig. 1.) No such similarity in the variations of temperature from decade to decade could occur at these stations if artificial heating produced an appreciable effect upon the mean temperature of the free air where the records were made.

[Dotted lines indicate excess or deficiency of average temperatures for the later decade as compared with those of the earlier decade designated in the margin.]



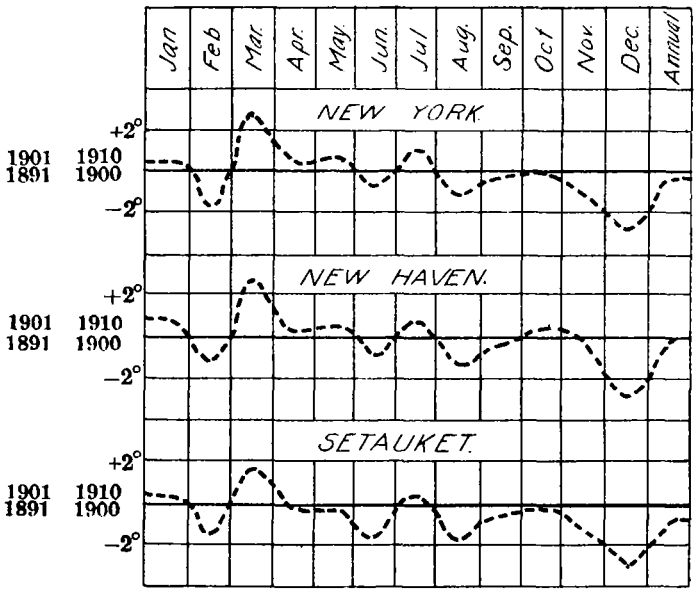


FIG. 2.—Showing similarity of temperature variations at New York and other stations.

Comparing the mean monthly and annual temperatures for the last 30 years at New York with those for 30 years ending in 1851 at the same place, we find that the temperatures for the last 30 years are higher than those

of the earlier period, except in July, but the differences are slight, amounting to only half a degree for the year, with a maximum of 1.9° in September. (See fig. 2.) A similar comparison based on the records for New Haven shows substantially the same variations. These differences appear very small when we remember that in the course of so many years the position of the instruments, the hours of observation, the observers, and the methods of computing the mean temperatures have all been changed one or more times, and probably the instruments also. A difference of half a degree or more in the mean annual temperature might result from a single circumstance, such as a change in the position of the instruments or the adoption of a new method of reducing the observations, though it is presumed that variations due to such causes counterbalance each other to some extent. However, the differences between the earlier and later 30-year periods at New York and New Haven are so nearly equal as to indicate that they are due to general, not local, conditions.

In support of the belief that the climate of cities is subject to changes induced by artificial heating, it has been stated that the frequency of temperatures as low as or lower than zero has shown a marked falling off at New York in recent years, particularly since 1904. The truth of this assertion is granted, but a period of six years is entirely too short a period on which to base a general statement relative to climatic changes. For the last three decades the number of days with temperatures of zero or below at Atlantic City was successively 5, 8, and 1; at New York, 5, 7, and 4; at New Haven, 30, 23, and 23. That the last decade gave the smallest number of days with zero weather at the three stations accords well with what has been shown in the study of the accompanying tables, and there is no reason to suppose that slight changes from higher to lower temperatures and from lower to higher will not occur again and again in the future as they have in the past.

Methods of study similar to those employed in the case of temperature have been applied to the precipitation records for quite a number of stations, and the principal results are set forth in Tables 2 and 3. The general agreement of the variations in the rainfall at New York with those at the other stations, as shown in Table 3, is a reliable evidence that the alternation of periods of wet and dry years at New York has been brought about by causes that, with a few local exceptions, affected the entire region from the vicinity of Philadelphia to the middle Hudson Valley and central Connecticut. Comparing the mean annual amounts of precipitation for the 30 years ending in 1856 and the 30 years ending in 1910 a higher average was found for New York during the later period, while lower averages were obtained in the cases of Albany and Philadelphia. It is worthy of note that the greatest decrease happens to have occurred in Albany, where the amount of heat artificially produced is insignificant compared either with that in Philadelphia or New York. A matter of greater importance, however, is the fact that, in all the longer records, a decrease in the mean annual precipitation is invariably followed by an increase, and there is no more reason for supposing that a present decrease will be permanent in one case than an increase in another. Examination of the monthly amounts of precipitation at New York during the last 40 years has failed to show any evidence of greater drought in the winter seasons of recent years, though a study of only the last 10 or 20 years might lead to the belief that the winters are becoming permanently drier. The writer finds that only March, July, and November have had less precipitation in the last decade than in any other since 1870, while the amounts for January, February, May, and October were least in the decade ending in 1880.

Nowhere in the study of the precipitation records has there been found any evidence of decreased rainfall such as should result from higher temperatures artificially produced. Were it possible to raise the average temperature of the free air by artificial means, there can be little or no doubt that a decrease in relative humidity, cloudiness, and precipitation would follow. The relative humidity and the degree of cloudiness have not been recorded with sufficient precision to justify a study of the records of these elements in this connection, but as there is no satisfactory evidence either of increased temperature or decreased precipitation, except such as has been shown to result from natural causes, the assumption that artificial heating has affected the true climate of any city is not warranted.

TABLE 1.—*Mean temperatures, by decades.*

Stations.	1861–1870.	1871–1880.	1881–1890.	1891–1900.	1900–1910.
New York City	52.3	51.2	51.7	52.5	52.3
New Haven, Conn.	49.1	49.6	48.9	49.7	49.7
Setauket, N. Y.				51.2	50.4
Philadelphia, Pa.		53.2	54.0	54.5	54.1
Atlantic City, N. J.			51.9	52.4	52.2

TABLE 2.—*Mean annual precipitation, by decades.*

Stations.	1831–1840.	1841–1850.	1851–1860.	1861–1870.	1871–1880.	1881–1890.	1891–1900.	1901–1910.
Philadelphia, Pa.	42.41	45.52	43.06	49.37	42.69	39.57	38.63	43.39
Rancocas, N. J.					46.73	46.28	44.15	48.53
Moorestown, N. J.					42.32	45.01	47.28	48.78
Atlantic City, N. J.						44.51	35.18	35.26
Dover, N. J.							46.85	54.45
Paterson, N. J.						54.16	47.93	51.09
South Orange, N. J.					44.54	50.28	48.56	48.16
Newark, N. J.			44.91	47.44	47.59	49.59	47.66	49.08
Elizabeth, N. J.						50.41	48.78	45.81
Central Park, N. Y.					43.58	44.44	41.40	44.10
New York City	34.93	38.31	40.83	45.15	42.81	48.06	42.45	43.48
Setauket, N. Y.							46.22	44.47
Wappingers Falls, N. Y.							45.89	53.13
Hartford, Conn.					40.94	44.15	43.92	45.49
New Haven, Conn.						47.27	42.30	44.76
Albany, N. Y.	40.89	42.47	36.82	39.57	40.63	38.55	34.37	32.14

TABLE 3.—*Variations in mean annual precipitation, by decades.*

Stations.	1840–1850.	1850–1860.	1860–1870.	1870–1880.	1880–1890.	1890–1900.	1900–1910.
Philadelphia, Pa.	[1]+3.11	−2.46	+6.31	−6.68	−3.12	−0.94	+4.76
Rancocas, N. J.					−0.45	−2.13	+4.38
Moorestown, N. J.					+2.69	+2.27	+1.50
Atlantic City, N. J.						−9.33	+0.08
Dover, N. J.							+7.60
Paterson, N. J.						−6.23	+3.16
South Orange, N. J.					+5.74	−1.72	−0.40
Newark, N. J.			+2.53	+0.15	+2.00	−1.93	+1.42
Elizabeth, N. J.						−1.63	−2.97
Central Park, N. Y.					+0.86	−3.04	+2.70
New York City	**+3.38**	**+2.52**	**+4.32**	**−2.34**	**+5.25**	**−5.61**	**+1.08**
Setauket, N. Y.							−1.75
Wappingers Falls, N. Y.							+7.24
Hartford, Conn.					+3.21	−0.23	+1.57
New Haven, Conn.						−4.97	+2.46
Albany, N. Y.	+1.58	−5.65	+2.75	+1.06	−2.08	−4.18	−2.23
Number of variations agreeing in character with New York (total 34)	2	0	3	2	5	11	11
Disagreements (total 12)	0	2	0	2	3	1	4

[1] This indicates that the precipitation for the 10 years ending in 1850 averaged 3.11 inches greater than for the preceding decade, and so on throughout the table.